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Preliminary Study: Treatment Of Food Industry Wastewater Using Two-Phase Anaerobic Treatment System

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Abstract: Food industry wastewater is well known for its high concentration of COD and suspended solid. The condition of the wastewater formed makes it illegal for the industry to release the wastewater to the open body of water without proper essential treatments. The study is conducted on wastewater produced by a food processing company which specializes in chips export business. A two-phase anaerobic treatment systems involving UASB and HUASB reactors as primary treatment and followed by AF reactor as secondary treatment are proposed. In this study, the performance of UASB-AF (R1) and HUASB-AF (R2) was monitored, and the effectiveness of palm oil shell as support media was evaluated as well. Parameters measured are pH, COD, NH_3-N, oil and grease and total phosphorus (TP). The instruments used for collecting data in this research are pH meter and HACH DR5000. It was found that the highest COD removal for the effluents from the R1 system,R1-U and R1-AF were on day 14 with 93.6% removal and on day 62 with 96.6% each. Meanwhile, in the R2 treatment system, the highest COD removal for the effluents from the R2-H and R2-AF were on day 14 with 98.3% removal and on day 110 with 97.6% removal. This study has generate useful findings that could be applied to alleviate the current problem at the food factory and also at other food industry in the future.

Keywords: Food industry wastewater, two-phase anaerobic treatment system, UASB, HUASB, AF, palm oil shell

1. Introduction

Water is a compound that is important to all living things in this world. 70.9% of the Earth's surface is covered with water. The ocean holds about 97% of surface water, the glaciers and polar ice caps holds 2.4%, while the other 0.6% of water in this world can be found at lakes, rivers and ponds. Unfortunately, the water quality in this area has deteriorated from time to time due to human's bad practices. One of the reasons for this is due to production of wastewater; comprises of liquid waste discharged by domestic residences, commercial properties, industry and agriculture that cover a broad range of potential contaminants and concentrations.

One of the industries that produce wastewater that can contaminate the environment is chip industry. The chips manufacturing wastewater contains high concentrations of several organic compounds including carbohydrates, starches, proteins, vitamins, pectines and sugars which are accountable for high chemical oxygen demand (COD) and suspended solids (SS) [1]. The wastewater resulted from a series process that includes the material getting, storing, cleaning, shelling, choosing and cutting, slicing, washing, frying, salting, picking, coating and packing in step by step, is a significant source in environmental pollution. As a rule, wastewater streams with different levels of pollution load (low, medium and high contamination) are collected and treated in an on-site installation or in a municipal sewage treatment plant [2].

There are various treatments that can be applied to treat wastewater produced by the industries. Biological treatment is one of the most efficient treatments that consist of aerobic and anaerobic treatment. The commonly preferred treatment is anaerobic treatment due to its low cost and effectiveness. One of such of the anaerobic bioreactor is an upflow anaerobic sludge blanket or UASB bioreactor which comprises a popular design with successful applications for treatment of high strength industrial wastewater, especially those from food processing and pulp and paper industries [3]. The main aspect of this process is the nature of the active biomass which will degrade the contaminants [4]. The formation of anaerobic granular sludge can also be considered as the major reason for the success of UASB treatment [5]. The biomass growth will later affect the settleability of the sludge which is in the form of spherical flocs with a quite consistent structure, normally referred to as granular sludge.

Other than UASB reactor, another reactor that makes use of the granular sludge as a key to treat wastewater is the hybrid-UASB or HUASB. Following the uprising popularity of the UASB, the HUASB reactor has also been successfully introduced to the public as a clean-efficient technology. Basically, HUASB is a combination of the UASB and anaerobic filter (AF) reactors. The only difference in HUASB and UASB is that there is a presence of a filter cage in HUASB bioreactor which

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makes use of media; such as palm oil shell to enhance contaminant removal. But still, it is reported by many researchers that both UASB and HUASB provide good treatment [6].

There are lots of applications of UASB and HUASB reactor in treating the wastewater resulted from the manufacturing in the industries. The performance of UASB and HUASB in some application in industries is tabulated as in Table 1 and Table 2.

Table 1 Performance of UASB in COD Removal of Several Types of Wastewaters.

Sample	COD removal
POME [7]	90 %
Synthetic wastewater [8]	92-96%
Domestic wastewater [9]	79-89%

Table 2 Performance of HUASB in COD Removal of Several Types of Wastewaters

Sample	COD removal
Dairy wastewater [10]	97-99%
Pharmaceutical wastewater [11]	85-99%
Poultry slaughterhouse wastewater [12]	80-92%
Palm Oil Mill Effluent [13]	84-91%
Palm Oil Mill Effluent [14]	~ 97%
Palm Oil Mill Effluent [15]	~ 93%

Other than UASB and HUASB, another treatment that applies the concept of anaerobic biodegradation is anaerobic filter (AF). Biological filtration is a standard treatment for wastewater. Biological filtration as the name states encourages microbial growth in filters to enhance their performance beyond solely physical filtration. Microorganisms existed will consume or digest organic matter in the wastewater which includes removal of nitrogen, phosphorus and other organic matter [16]. There are many application of anaerobic filter in treating various wastewaters. The examples are shown in Table 3.

Table 3 Performance of AFin Treating Several Types of Wastewaters

Sample	COD removal
Food industry wastewater [16]	82-93%
Synthetic wastewater [17]	80-84%
High-strength sulphate-rich Leachate [18]	73-91%

The two-stage anaerobic digestion process provides good stability to the microorganism's growth and allowing more specific control for each reactor which will enhance the efficiency of treatment. Through phase separation, prevention of formation of intermediate metabolic compounds such as volatile fatty acids (VFA) that can inhibit methanogenic step can be achieved. This is due to the different growth rates and optimum pH for the development of acidogenic (low pH) and methanogenic (slightly alkaline) organisms supports the idea of two-stage anaerobic process [19].

As we mentioned HUASB and AF, one of the main components in the reactor design is the support media. Natural low-cost materials such as shells, sawdust, peat, coal ash, granite stones, cinder, brick ballast, glass, and many other materials are commonly used as the support material in bioreactor. The role of support media as a surface for biofilm attachment and entrapment provides great impacts on wastewater treatments [17]. The media is generally chosen based on their degree of porosity, surface roughness and pore size**.** Generally, there are lots of potential support media to be applied in the bioreactors and to be studied on their performances. Agriculture waste such as palm oil shell is one of the potential support media existed and to be studied in this research.

2. Methodology

2.1 Experimental Setup

Two Perspex laboratory-scaled UASB and HUASB reactors were used in this experiment. The UASB and HUASB reactors were operated with height of 75 cm and 10 cm diameter each. One of the reactors was added with a filter cage; modifying it into a hybrid-UASB.

After being treated in the UASB/HUASB reactor, the effluent from the UASB/HUASB reactors had undergone another treatment in the AF. The AF reactor was be 6000 cm^3 (20 cm x 10 cm x 30 cm) in dimension. The filter media (palm oil shell) were filled into the anaerobic filter as support media to promote the growth of microorganisms on their surface. To simplify the matter of operation, the list of reactors and particulars involved during the operation is tabulated as in Table 4.

Table 4 List of Reactors and Particulars Involved in Each Set of Treatment System

Set	Primary Treatment	Secondary Treatment	Media
R1	R1-U (UASB)	R1-AF	Palm oil shell in AF
R2	R2-H (HUASB)	R2-AF	Palm oil shell in HUASB and AF

Basically, the wastewater will be treated by UASB/HUASB reactor first, and later by AF reactor. Overall, the schematic diagram of UASB-AF and HUASB-AF treatment systems can be illustrated in Fig. 1.

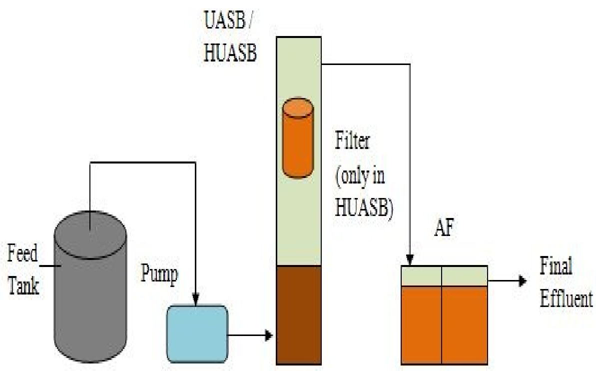

Fig. 1 Design for UASB-AF (R1) and HUASB-AF (R2) treatment system

During the experiment, some variables were controlled such as OLR, HRT, and temperature in order to find the most suitable OLR for the bioreactors. Table 5 shows the operational conditions of the treatment systems for the UASB/HUASB and the AF.

Table 5 Operational Conditions ofthe UASB/HUASB and the AF Reactors

Operation Condition	Unit	UASB/HUASB	AF
Working Volume	Litre, L	5.893	6.0
OLR	g COD/L.d	2.37 and 3.19	2.32 and 3.14
HRT	Day	2.04 and 1.5	2.08 and 1.2
Temperature	^{0}C	Both at ambient temperature	

2.2 Sampling

Throughout this research, UASB/HUASB reactors were seeded with sludge collected from the anaerobic pond at the Kahang Palm Oil Mill. The anaerobic sludge was chosen due to its already existing anaerobic microorganism's population in it. The raw sludge was screened to remove coarse solid which may inhibit the anaerobic suspended growth. Then, the sludge was placed into the reactors respectively.

The support media that were to be used in this research is palm oil shell (POS). The POS was taken from Palm Oil Mill at Kahang. The palm oil shells taken from the mill will be seized to obtain media with range of 5.0 mm to 10.0 mm. Before being placed into the filter in HUASB and AF, the media were mixed with sludge obtained from anaerobic pond at Kahang Palm Oil Mill (the same sludge used in UASB and HUASB) to activate it with microorganism populations. Then, the media was placed into HUASB and AF respectively. In this research, the sample of food industrial wastewater was taken from Azhar Food Manufacturing factory, Rengit, Johor. The sample was taken freshly during manufacturing process was in place. The sample was placed into refrigerator, around 4 ^{0}C to avoid biodegradation of sample before being treated. Due to the solid content (leaves, tree branches from surroundings and others) in the wastewater, the raw sample undergone screening before being transferred into the feed tank.

2.3 Start-up Period

The sample was pumped into the UASB and HUASB reactors and the steady-state achievement which can be determined through stable biogas production and 90% COD removal. The reactors were monitored for lookout of biomass washout, overloading and other unwanted phenomenon. During the beginning stage of start-up period, the biomass particles tend to aggregate as a result of microbial cells excretion. This aggregation phases is said to be highly sensitive process which is sensitive to operational parameter's shock, including temperature and OLR. Thus, it is important to maintain for any changes during this period. The purpose for start-up period will be for the granule development to achieve its steady or optimum state.

2.4 Data Analysis

In this research, the influent (from the feed tank) and the effluent from UASB and HUASB and also from the AF were analyzed to identify the performance of the system. The parameters analyzed were COD, pH, nitrogen-ammonia, oil and grease value and total phosphorus concentrations.The COD, nitrogen-ammonia and total phosphorus concentrations were determined using DR5000 spectrophotometer while the oil and grease concentration was determined using the standard method APHA. Each samples were analyzed with three replicates to ensure precise readings.

3. Results and Discussion

3.1 Reactor's Performance

During the earlier start-up period, the COD removal for R1 and R2 were already high since the very beginning of treatment. This was due to the already living microbial population in the sludge bed. But then, the efficiency decreased in both R1 and R2 at the beginning stage after a few moment of splendid removal as some bacteria dies at the early stage as they acclimatizes. For R1, the population observed to be able to adapt to the system and starts acclimatizing since the 40th day as the COD removal begins to have stable patterns and constant readings. On the other hand, for R2, the population seems to be acclimatizing beginning on the 32nd day as since that day the COD removal keep increasing until achieving its steady state. The reactor systems achieved their first steady state on day 66th for R1 and 64th for R2. After increasing the OLR from 2.3 g COD/L.d to

3.19 g COD/L.d for both systems after achieving steady state, it was observed that there were slight decreased of removal efficiency as the microbial populations were adjusting themselves to the new OLR.The percentage of COD removals for R1 and R2 are as demonstrated in Fig. 2 and Fig. 3.

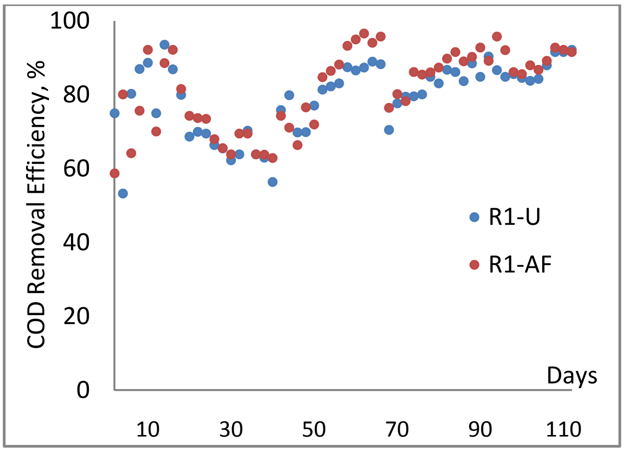

Fig. 2 COD removal in R1 system

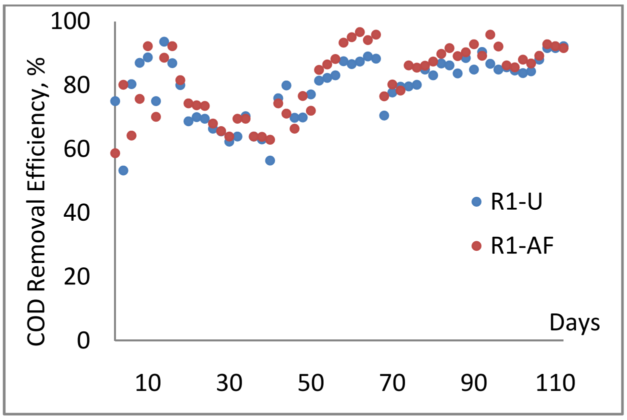

Fig. 3 COD removal in R2 system

The raw food wastewater used in this research has a pH value around 4; acidic properties. The pH reading of effluents for R1 was lower during the beginning of the treatment. It was found that the fermentation of simple sugars can occur between pH 4.5 and 7.9; although it is likely to prefer pH of between 5.7 and 6.0 [20]. The wastewater in this range of pH will enable the acidogenic bacteria to grow as it begins digesting. However, starting from the 44th day and onwards, the pH readings of the effluents from R1 system increased from around 6 to 8. This range of pH will allow the methanogenic bacteria to start growing and completing the digestion [21]. For R2, the pH reading was always around 6-8; which is more ambient for the methanogenic bacteria to live than the acidogenic bacteria. Although this occurred, based on the COD removal, it was observed that the hydrolysis and acidogenesis stage went just fine. The pH reading of effluents from R1 and R2 were as in Fig. 4 and Fig. 5.

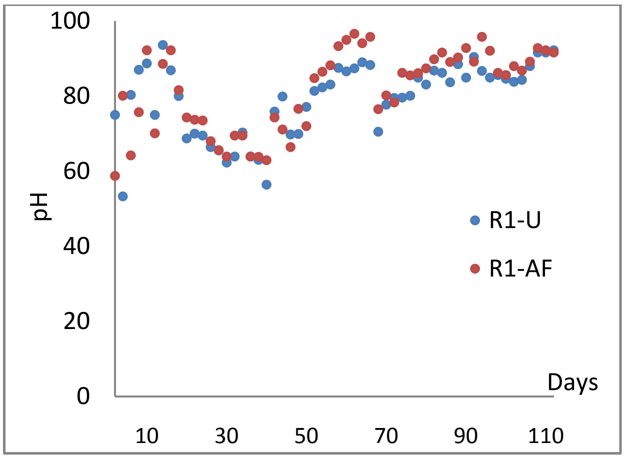

Fig. 4 pH of effluent from R1 system

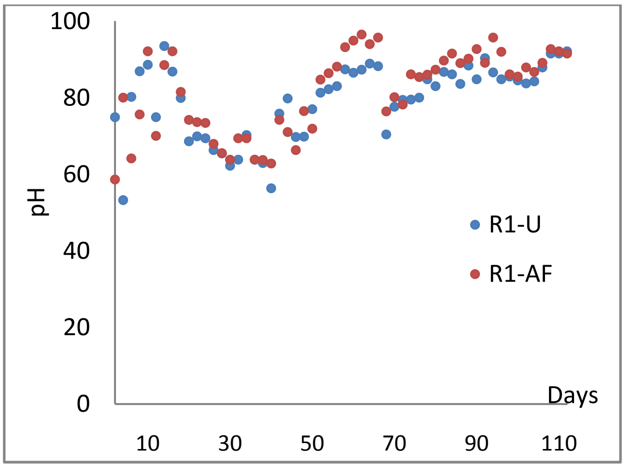

Fig. 5 pH of effluent from R2 system

3.2 Nutrient consumption

During the beginning of the treatment, there were some increased of total phosphorus and nitrogen-ammonia concentration of the effluent from the reactors. This was due to the interaction of the wastewater with the sludge bed where the bad settling impurities tend to float and mix with the sample feeded in the reactors. However, after around 20 days, the bad settling particles were able to be degraded and flushed out out of the reactors for both R1 and R2 systems.The TP and N-NH_3concentrations in R1 and R2 systems were illustrated as in Fig. 6 to Fig. 9.

As the treatment operation progressed, the phosphorus concentration decreases. This was due to the good development of biomass inside the reactor that would increase the efficiency of the reactors. However, due to the shock ofhigher loading application after each steady state, the phosphorus concentration easily escalated. This occurred due to the floatation of bad settling particles as higher loading rate were applied.

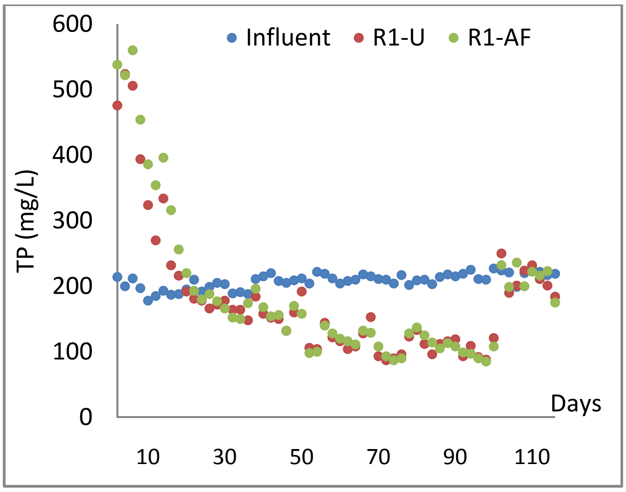

Fig. 6 TP value in R1 system

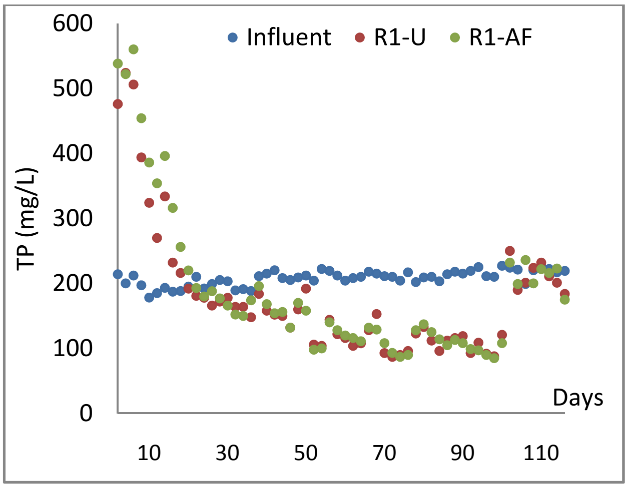

Fig. 7 TP value in R2 system

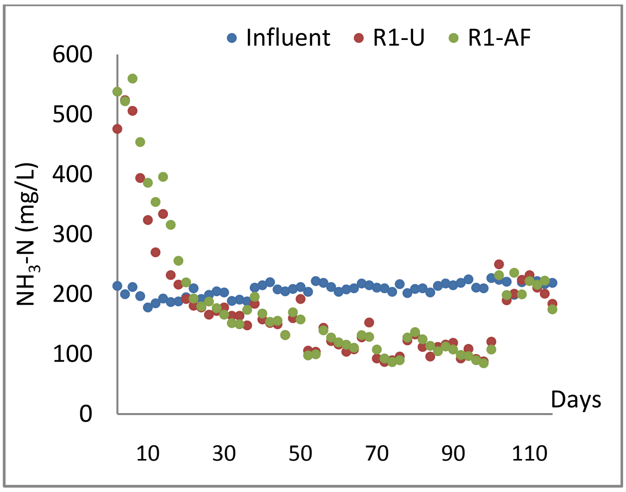

Fig. 8 NH_3-N value in R1 system

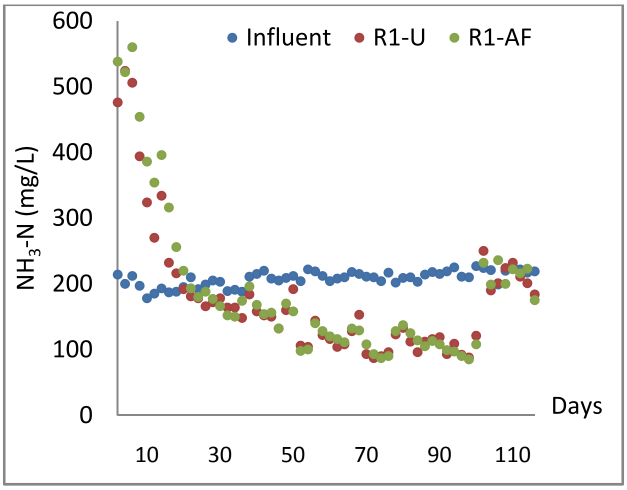

Fig. 9 NH_3-N value in R2 system

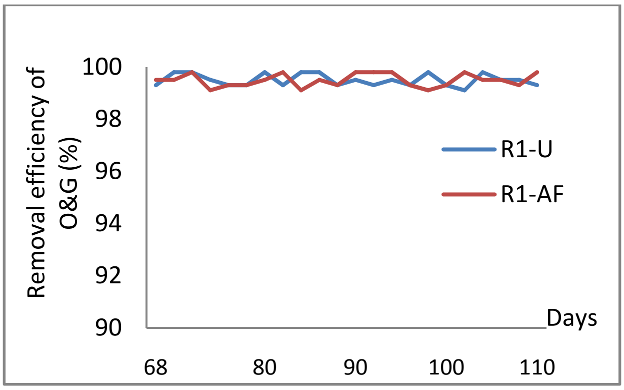

Fig.10 Removal Efficiency of O&G for R1 system

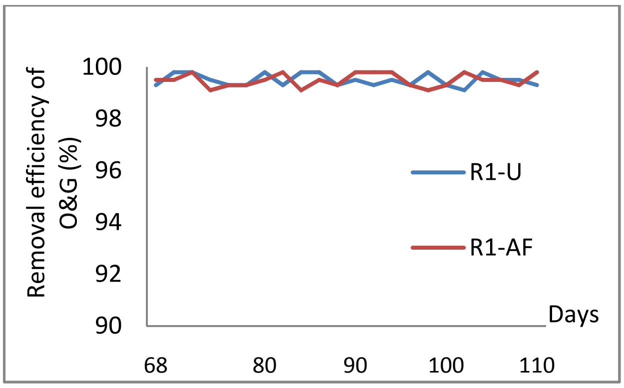

Fig.11 Removal Efficiencyof O&G for R2 system

On the other hand, the NH_3-N value resulted in negative removal ever since the beginning days of the treatment. This was due to the bad settling impurities that floated and mixed with the influents. However, the bad settling particles should be gone from the reactors after around 20 days of treatment.Thenegative removal efficiency was due to the biodegradation of the contaminants into simpler organic acids. This could include conversion of the proteins into amino acids through the microbial reaction which affects the ammonia nitrogen concentration in the effluent [19].

3.3 Oil and Grease (O&G) Removal

The sample use in this study was taken from food manufacturing industry which specializes in chips manufacturing. This causes the wastewater to become oily and thus polluting the environment and also the water body. The influent of the wastewater sample has the concentration of oil and grease around 17 mg/L whereas according to Environment Quality (Industrial Effluents) Regulations 2009 of Malaysia [22], wastewater released from an industry should not have concentration of oil and grease more than 10 mg/L when they are being released to an inland water body which is out of the industry's catchment. In this research, the removal efficiency of the food industrial wastewater shows achievements of more than 95% oil and grease removal (around 1 to 2 mg/L left in the effluent). Fig. 10 and Fig. 11 shows the oil and grease removal efficiency from R1 and R2 treatment systems.

4 Conclusion

This paper enlightens the possible alternative of fusing two anaerobic bioreactors to form a stable treatment system while enhancing the efficiency to treat problematic food industry wastewater. In the R1 treatment system operated, the highest COD removal for the effluents from the R1-U and R1-AF were on day 14 with 93.6% removal and on day 62 with 96.6% each. Meanwhile, in the R2 treatment system, the highest COD removal for the effluents from the R2-H and R2-AF were on day 14 with 98.3% removal and on day110 with 97.6% removal. Besides that, the pH of the effluent seems to rise to become more basic than the influent. On the other hand, up till now, the nutrient consumption of the systems seems more beneficial to the digestion of TP than the NH_3-N. The nutrient consumption in the bioreactors would be investigated more at higher loading rates. To conclude, based on the COD removal, the R2 treatment system seems to be more in favor due to its shorter time needed to achieve steady-state and consistently stable removal efficiency. In addition, the idea of using palm oil shell as support media for attachment, entrapment and development of the biofilms on the surface that were applied in the HUASB and AF reactors seems reliable and more research on it is necessary.

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